

X-Band Tracking Operations During the Viking Orbital Phase

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X-band tracking of the Viking spacecraft in orbit around Mars will be complicated due to the combination of high periapsis doppler rates and low downlink carrier margin. This report presents methods to implement X-band tracking of the Viking spacecraft by ramping either the ground transmitter frequency or the ground receiver frequency. The operational impact of the two methods is assessed.

I. Introduction

Tracking at the 64-m deep space stations with the Block IV X-band receiver in a 10-Hz tracking loop filter setting will be quite difficult at Viking Orbiter periapsis because of high doppler rates. As an alternative, use of the 30-Hz tracking loop filter during Block IV X-band tracking is not promising because there is only marginal carrier power above threshold (~ 8.7 dB) in this mode. Additionally, it had been thought (Ref. 1) that in order to maintain a reasonably small phase error while tracking with the Block IV X-band receiver in a 10-Hz tracking loop filter setting, as many as 20 digital controlled oscillator (DCO) ramps (frequency rates) per periapsis pass might be required. It is therefore the intent of this report to analyze in greater detail the operational capabilities and constraints while tracking a Viking Orbiter with the Block IV X-band receiver(s) in a 10-Hz tracking loop filter setting.

II. Orbits Utilized in the Analysis

Reference 2 analyzed in great detail four separate orbits. These consisted of permutations of periapsis altitudes of 1200 and 500 km and of lines of apsides either normal to or parallel to the Mars-Earth vector. These can be abbreviated as 500 km/N, 500 km/P, 1200 km/N and 1200 km/P. The highest periapsis doppler rates are encountered with the 500 km orbits, so it was considered adequate to limit this analysis to the 500 km/P- and 500 km/N-type orbits. The periapsis doppler rates (X-band, two-way) for these two orbit types can be seen in Figs. 1 and 2, respectively.

III. Consideration of Static and Dynamic Phase Error

In the initial consideration of the adequacy of a given receiver to track a given signal, one is concerned with both the static phase error (SPE) due to frequency dis-

placement and dynamic phase error ($\Delta\theta$) due to frequency rate. As it turns out, the pacing criterion for the worst Viking orbital case (the 500-km/P-type orbit), in terms of necessary ramping of the X-band receiver, is the dynamic phase error, and hence this study will be mostly focused on this particular parameter. Also, any receiver ramping schemes which will alleviate the dynamic phase error problem, coupled with judicious choices of starting receiver frequencies, will almost automatically keep the total frequency displacement small, and hence negate most static phase error buildup. Quite simply, if one is ramping the receiver to keep the received frequency rate within certain bounds as in Fig. 3, the cumulative frequency displacement

$$\sum_{n=1}^i \int_{n-1}^n \left\{ R_n - \frac{d}{dt}(D2) \right\} dt \sim 0$$

(where R_n is the receiver ramp rate and $d/dt(D2)$ is the received doppler rate) is relatively small when compared to that frequency displacement which would result from no ramping of the receiver.

IV. Analysis of Receiver DCO Ramps to Maintain Dynamic Phase Error Below 13 deg

Rather arbitrarily selecting a (conservative) objective of maintaining the phase error ($\Delta\theta$) at 13 deg or less, one has the following pertinent information from the DSN/Flight Project Interface Design Handbook (Ref. 3) and from Ref. 1:

Block IV X-band receiver carrier margin at 10 Hz tracking loop filter ≈ 13.51 dB

Downlink frequency rate required to produce $\Delta\theta = 13$ deg at a carrier margin of 13.5 dB $\approx \pm 15$ Hz/s.

The periapsis 2-way X-band doppler frequency rates versus time for the 500-km/P-type and 500-km/N-type orbits are shown in Figs. 1 and 2, respectively. Overlaying the doppler frequency rates in Figs. 1 and 2 are the required receiver ramps to keep the dynamic phase error approximately equal to or less than 13 deg, and hence from the information above, to keep the (relative) frequency rate at the receiver (= downlink frequency rate minus receiver ramp rate) approximately equal to or less than ± 15 Hz/s. As can be seen in Fig. 1, the 500-km P-type orbit is the more extreme case, requiring 11 re-

ceiver DCO ramps during the periapsis period. The 500-km/N-type orbit (see Fig. 2) is only slightly less difficult, requiring 8 receiver DCO ramps during the periapsis period.

V. Error Analysis

In the previous section the number of receiver DCO ramps required to produce a $\Delta\theta$ of 13 deg or less was analyzed; however, this (implicitly) assumed that the predictions used to generate the required ramp parameters would be perfectly matched to the actual data. At this point it would be reasonable to briefly examine the effect of using (slightly) inaccurate predictions.

Let one assume that a reasonable goal would be the generation of a ramp scheme designed to keep $\Delta\theta$ at 13 deg or less, but that one would tolerate occasional $\Delta\theta$'s of up to 17 deg because of inaccuracies in the predictions. Given this ground rule, one needs to determine what magnitude of prediction error would cause a combined $\Delta\theta$ of 17 deg, and, if one could expect prediction errors for the Viking orbital phase to be bounded by this (to-be-determined) prediction error. For a $\Delta\theta = 17$ deg, one has from Ref. 3, the following received doppler frequency rate: $\approx \pm 20$ Hz/s. Differencing this value with the ramp scheme goal of ± 15 Hz/s for the (relative) received frequency rate, one wishes to determine what size prediction error would thus cause a two-way X-band doppler frequency rate error of $\approx \pm 5$ Hz/s.

For both the 500-km N-type and 500-km P-type orbits, the maximum rate of change of frequency rate is

$$\left\{ \frac{d}{dt}(\text{frequency rate}) \right\}_{\max} \gtrsim (10 \text{ Hz/s})/\text{min}$$

such that a frequency rate error would translate into an equivalent (prediction) time error of

$$\Delta t = \frac{5 \text{ Hz/s}}{(10 \text{ Hz/s})/\text{min}} \approx 30 \text{ s}$$

If recent past experience with respect to prediction accuracy at planetary encounters, etc., proves to be a reliable guide, one can indeed expect that, in general, trajectory errors during the Viking Orbital Phase will be less than 30 s (Δt), and hence expected errors in the prediction data from which ramp rates will be generated should add less than 4 deg of $\Delta\theta$.

VI. Operational Considerations

Let one consider the simplest case of just one receiver—a Block IV X-band receiver in the two-way mode with a 10-Hz tracking loop filter setting. If one considers a 500-km P-type orbit, and using the criterion previously established in Section IV, 11 separate ramps will have to be programmed into the receiver DCO per periapsis pass. At the DSS the operation will be complicated because the DCO holds only 4 ramps at any given time, and, as the initial ramps are executed, subsequent ramps will have to be manually entered into the DCO in near real time. Additionally complicating the receiver operator's job is the fact that the ramps are exhausted in as little as three minutes, thus allowing little time for the operator to enter and verify new ramps.

Generation of the ramp instructions in the Network Operations Control Area (NOCA) should also prove to be difficult, and in particular, time-consuming. Receiver frequency predictions are not generated in the prediction system, and the only method by which they can be generated (now) is manual, with the aid of Hewlett-Packard Programmable Electronic Calculators. Also, the Block IV DCO receiver frequency level is quite unfamiliar to most of the Network Operations Control Team (NOCT). Finally, assuming the ramp instructions are generated by the NOCT, they will have to be transmitted manually (via teletype) to the DSS, with a greatly increased risk of transmission errors, etc.

The above considers only the difficulties in ramping one receiver. If the Block IV S-band receiver is also in a 10-Hz tracking loop filter configuration, it too will require ramping, under some circumstances. Consider a 500-km P-type orbit. The maximum frequency rate at X-band (two-way) is ≈ 160 Hz/s. Thus at S-band it would be $\approx (3/11) \{160 \text{ Hz/s}\} \approx 44$ Hz/s. From Ref. 2, the Block IV S-band receiver carrier margin equals 21.3 dB, so that (from Ref. 3), a phase error equal to 13 deg results from a receiver frequency rate of $\approx \pm 30$ Hz/s. Thus, to avoid excessive phase error, the Block IV S-band receiver will also require some ramping.

Finally, if three-way X-band doppler is ever desired from another 64-m DSS during a periapsis pass, the extremely laborious and time-consuming tasks described above will be doubled.

To summarize the above, receiver ramping during Viking Orbiter periapsis passes can be accomplished; however, it will:

- (1) Place additional burdens on the DSS receiver operator
- (2) Consume large amounts of manpower from the NOCT, because of the semimanual mode of receiver level ramp generation
- (3) Entail considerably more risk of error because of the manual mode (teletype) of transmission

VII. Use of Uplink Ramping

The idea of utilizing the DCO capability to ramp the uplink and thus reduce the total downlink frequency rate is obvious and certainly merits being investigated. For instance, considering the 500-km P-type orbit, the total periapsis 2-way doppler rate excursion is ≈ 170 Hz/s (-10 to $+160$). If one chooses and appropriately locates five uplink ramps at the following equivalent X-band frequency rates of $+10$, $+40$, $+70$, $+40$, and $+10$ Hz/s, then one will have modified the uplink such that the spacecraft will see a maximum frequency rate (at equivalent X-band level) of ± 15 Hz/s. More importantly one would reduce the total 2-way X-band downlink frequency rate excursion to ≈ 110 Hz/s (-20 to $+90$).

Instead of 11 DCO ramps in the receiver, one would now require only 7. However, 5 ramps are now required in the exciter, making a total of 12 ramps altogether. Considering the added complications of ramping the exciter and the receiver, it does not seem that ramping the uplink in the above described fashion will buy anything substantial.

A more interesting (although perhaps seemingly bizarre!) approach might be to consider over-ramping the uplink by a factor of 2. This poses no particular difficulty for the S-band spacecraft receiver, and, in any case, produces the same frequency rate at the spacecraft as if the uplink was not ramped at all. But more importantly, it should theoretically drive the downlink doppler frequency rate to some small limit such that the X-band receiver would not have to be ramped at all. As a matter of fact, this is exactly what happens. Quite simply, let one define at some time:

F_{2x} = two-way X-band downlink frequency

TSF = track synthesizer frequency (transmitted uplink frequency at DCO level, ≈ 44 MHz)

r_{up} = uplink range rate

r_{dn} = downlink range rate

c = speed of light

Then one has

$$\begin{aligned} F_{2x} \text{ rate} &= \frac{d}{dt} [F_{2x}] \\ &= \frac{d}{dt} \left\{ 48 \frac{880}{221} TSF \left[1 - \frac{(r_{up} + r_{dn})}{c} \right] \right\} \\ &= -48 \frac{880}{221} TSF \left\{ \frac{d}{dt} \left[\frac{(r_{up} + r_{dn})}{c} \right] \right\} \end{aligned}$$

Now if one assumes a ramped TSF , say TSF_R , and a corresponding F_{2x} , say $(F_{2x})_R$, one would have

$$\begin{aligned} (F_{2x})_R \text{ rate} &= \frac{d}{dt} [(F_{2x})_R] \\ &= \frac{d}{dt} \left\{ 48 \frac{880}{221} TSF_R \left[1 - \frac{(r_{up} + r_{dn})}{c} \right] \right\} \\ &= 48 \frac{880}{221} \left\{ \left[1 - \frac{(r_{up} + r_{dn})}{c} \right] \frac{d}{dt} (TSF_R) \right. \\ &\quad \left. - TSF_R \frac{d}{dt} \left[\frac{(r_{up} + r_{dn})}{c} \right] \right\} \end{aligned}$$

To drive the downlink doppler frequency rate to zero, one requires

$$\frac{d}{dt} [(F_{2x})_R] = 0$$

or

$$\frac{d}{dt} (TSF_R) = \frac{TSF_R \left\{ \frac{d}{dt} \left[\frac{(r_{up} + r_{dn})}{c} \right] \right\}}{\left[1 - \frac{(r_{up} + r_{dn})}{c} \right]}$$

since $1 \gg \frac{(r_{up} + r_{dn})}{c}$

$$\frac{d}{dt} (TSF_R) \cong TSF_R \left\{ \frac{d}{dt} \left[\frac{(r_{up} + r_{dn})}{c} \right] \right\}$$

and since $TSF_R \approx TSF$

$$\frac{d}{dt} (TSF_R) \cong TSF \left\{ \frac{d}{dt} \left[\frac{(r_{up} + r_{dn})}{c} \right] \right\}$$

Finally, from the previous definition of F_{2x} rate, one has

$$\begin{aligned} \frac{d}{dt} (TSF_R) &\cong - \frac{221}{48(880)} \frac{d}{dt} [F_{2x}] \\ &\cong - \frac{221}{48(880)} \{F_{2x} \text{ rate}\} \end{aligned}$$

Following the above logic, uplink ramps corresponding to those in Fig. 1 (approximately twice the uplink frequency rate and, of course, moved backward (earlier) from the times in Fig. 1 by one round-trip light time (RTLT)) were input into the 500-km P-type orbit predictions. The results in the downlink doppler frequency rate are just as expected—the X-band downlink frequency rate is constrained to ± 15 Hz/s. These results can be seen in Fig. 4. For this case no ramping of the receiver would be required. At first glance, it would not seem that anything of particular value has been achieved, since one now has 11 exciter ramps instead of 11 receiver ramps. However, on closer inspection, a number of operational benefits would appear to accrue, i.e.,

- (1) The uplink frequency level is far more familiar to the NOCT.
- (2) The necessary uplink ramp parameters can be obtained from prediction output quantities (XA and DD2) with far less effort than producing receiver level predictions and receiver level ramp parameters.
- (3) Uplink ramping requires no individual receiver frequencies, whereas receiver predictions require fairly current individual receiver parameters (the 21-MHz free-running oscillator) measured at the DSS.
- (4) Uplink ramps would routinely be transmitted within normal predictions (via high-speed data (HSD)) and would thus be virtually guaranteed free of transmission errors, in contrast to sending large amounts of receiver ramp data manually (via teletype).
- (5) When one considers the possibility of Block IV S-band tracking with a 10-Hz tracking loop filter, or, far more important, the addition of X-band 3-way tracking at a separate 64 m DSS, no additional receiver ramping is required, in marked contrast to the receiver ramping case, where the number of total required ramps increases by 100% or more—one ramped uplink covers all receivers!

In consideration of the above, the possibility of using overcompensated uplink ramping might merit further investigation.

References

1. Chaney, W., *High X-Band Doppler Offsets and Rates During Viking Orbital Phase*, IOM NSE-74-155, July 8, 1974 (JPL internal document).
2. Koerner, M., *Viking RF Receiver Phase-Locked Loop Phase Errors Produced by Spacecraft Motion*, IOM 3395-74-055, June 6, 1974 (JPL internal document).
3. *Deep Space Network/Flight Project Interface Design Handbook*, Document 810-5, Revision D, Feb. 15, 1975 (JPL internal document).

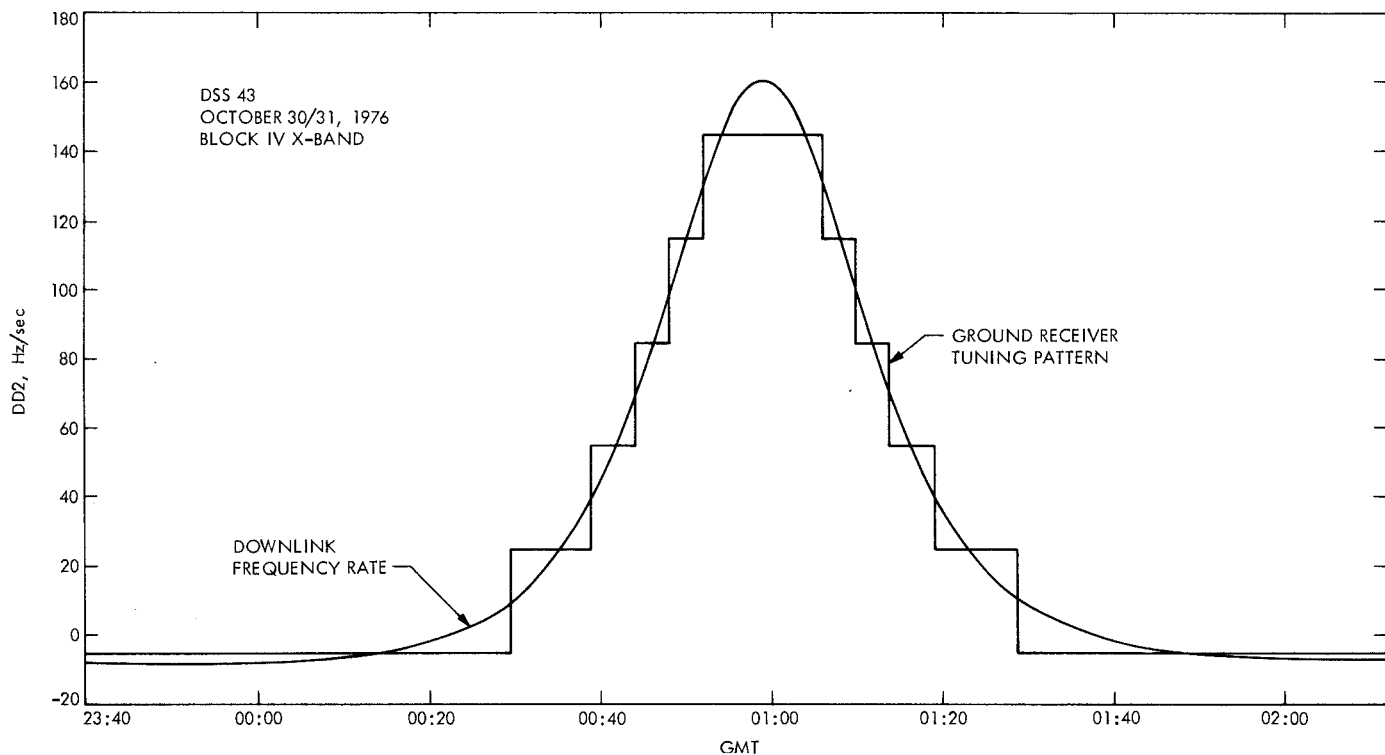


Fig. 1. Viking Orbiter 500-km/P-type orbit 2-way doppler rate versus GMT

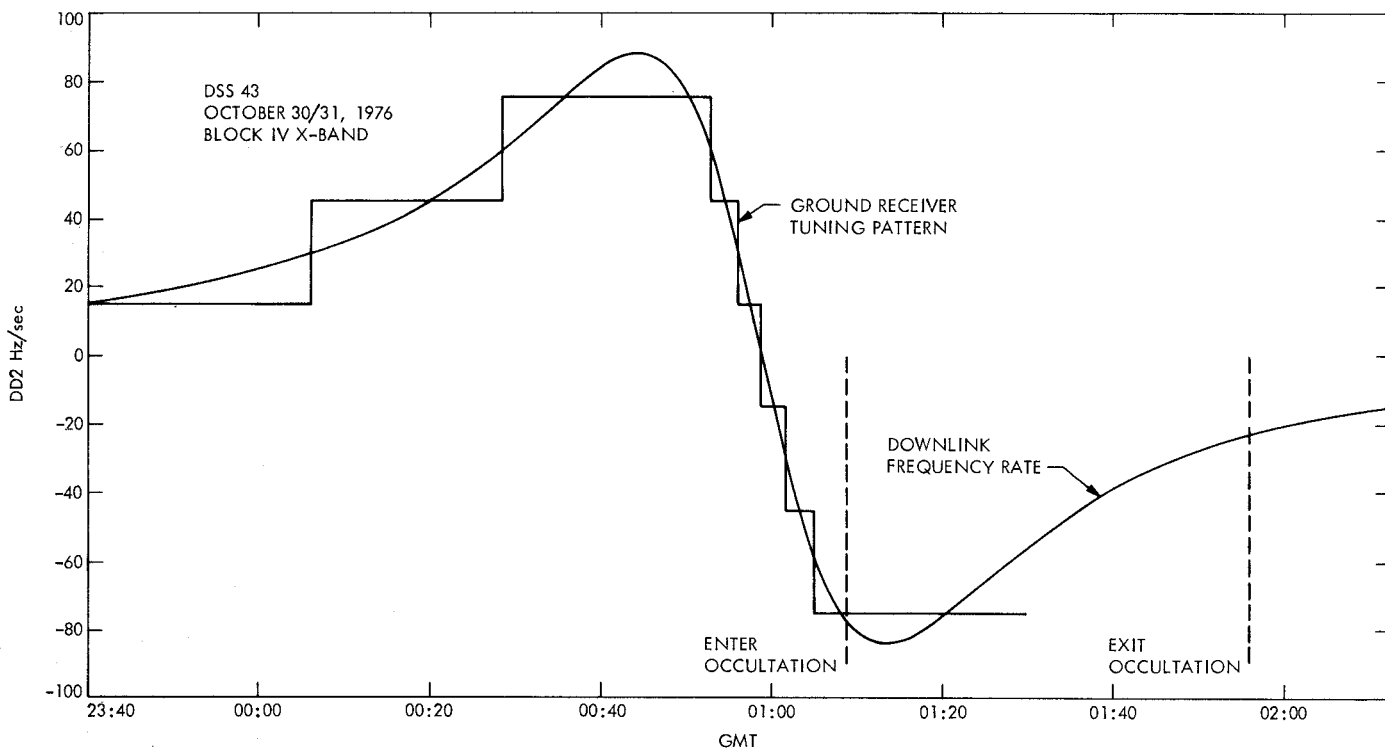


Fig. 2. Viking Orbiter 500-km/N-type orbit 2-way doppler rate versus GMT

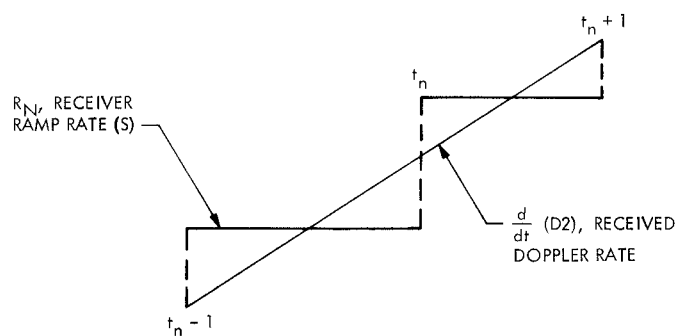


Fig. 3. Receiver ramp rates vs received doppler rate

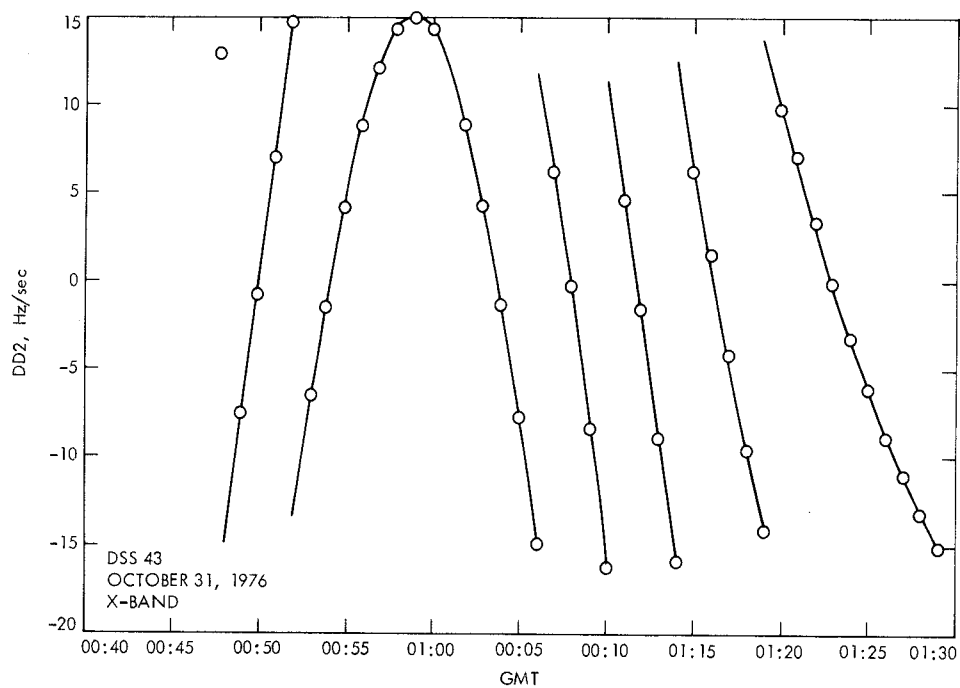


Fig. 4. D2 frequency rate with over-ramped uplink for Viking Orbiter 500-km/P-type orbit